A STUDY OF THE ECONOMIC DESIRABILITY OF COATING PIPE INTERNALLY TO REDUCE PRESSURE LOSSES

By

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1967

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1968

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PREFACE

The growth of the pipe line industry and the increasing costs of pumps and power have given rise to numerous ideas to cut these costs and to increase a line's capacity by reducing pressure losses. This research was done in an effort to determine if internal coating would decrease pressure losses and therefore decrease pumping and power costs adequately to make coating economically desirable.

I first became interested in this area while working at Continental Pipe Line in Ponca City, Oklahoma, in 1967. I wish to acknowledge my indebtedness to Mr. R. Thompson who provided the basis for this development.

I also wish to express my sincere appreciation to Dr. G. T. Stevens for his guidance and encouragement in writing this thesis.

Finally, special thanks are due Mrs. Patty Tillerson for typing this manuscript.

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CHAPTER I

INTRODUCTION

One method of reducing pumping and power costs is to reduce friction and pressure losses. In the pipe line industry many predictions have been made that internally coating the pipe will reduce the pressure losses. Companies that internally coat pipe have predicted reductions as high as 30 percent. These numbers mean very little without an analysis to prove whether they are economically desirable.

Pressure losses, when pumping a liquid, are a function of flow rate, size of conduit, length of conduit, viscosity of the fluid, relative elevation at both ends of the pipe and the relative roughness internally. Therefore if coating the internal surface of a conduit can reduce the relative roughness, a pressure loss reduction should occur.

The objectives of this research are to: (1) determine if an internal coating can reduce pressure losses from those observed under identical conditions in an uncoated pipe, (2) measure this reduction if it occurs, and (3) determine if internal coating is economical.

To accomplish the objectives of this research, two 2,000-foot test loops were constructed, one 2-inch loop and one 4-inch loop. Pressure losses were observed while pumping crude oil through the loop to establish the hydralic characteristics of the uncoated test loops. After initial runs were complete, a five-mil internal coating of epoxy resin was applied to both loops. Pressure losses were then observed on the coated loops while pumping the same liquid that previously had been used in the uncoated tests.

Pumping costs and power costs are related to pressure losses. If pressure losses can be reduced,then these costs can be reduced. The basic problem is, what percent reduction of pressure losses is necessary to reduce pumping and power costs to make internal coating economically desirable.

The remainder of this thesis is devoted to an elaboration of the concepts presented in this introduction with special emphasis on the economics of internal coating.

CHAPTER II

ANALYSIS AND TESTING

Economics on Internal Coating

As previously stated, an economic analysis is necessary to determine what percent reduction of pressure losses is required to reduce pumping and power costs to justify coating economically. Since pumping and power costs are related to pressure losses, then these costs can be reduced if pressure losses are reduced. While the internal coating reduces these costs, the cost of coating must be considered in the analysis. There must be a break even point where the coating is economically desirable. This analysis attempts to determine the percent reduction of pressure losses to produce this point.

Pressure losses are a function of the flow rate, size of conduit, length of conduit, viscosity of the fluid being pumped, relative elevation of the ends of the conduit, and the roughness of the inside of the pipe. All of these can be varied and therefore change the amount of pressure drop.

When there is no elevation change and pressure losses are expressed per unit of length, two of the variables can be ignored. The variables to be considered in this thesis are the rate, size of the conduit, viscosity, and the roughness of the internal wall of the pipe.

To make the analysis easier, some of these variables are held constant and others varied one at a time to determine the affect each has on the percent pressure loss reduction. Crude oil data used throughout the analysis allows the viscosity and specific gravity to be held constant. The two remaining variables, size of conduit and flow rate, are varied one at a time to determine their affect on the pressure loss reduction.

In the analysis only pumping costs, which include the initial cost of the pump and pump station, power costs, and coating costs are used to determine the break even point. Costs of maintenance, pipe, etc. are approximately the same for both the coated and uncoated loops and therefore are not included in the analysis.

Formulas Used in the Analysis

The formulas used in calculating the pressure losses and horsepower requirements are the "Pipe Line News" formulas (Thompson, 1967). They are

$$R' = \frac{Q}{dz}$$

$$R' = \frac{R}{2214}$$

$$f' = 34.9 \times f$$

$$P = \frac{f^1 Q^2 s}{d^5}$$

where:

R = Reynolds Number

Z = Viscosity-centistokes

f = Friction Factor

S = Specific Gravity

Q = Flow Rate-barrels per hour

P = Pressure Drop - psi/mile

d = Internal Diameter-inches

The Friction Factor versus Reynolds Number curve shown in Appendix A is used to obtain f', after R' is calculated. This curve is a plot of f' versus R', both of which are functions of f and R.

Other formulas needed are:

Convert psi/mile to $\frac{\text{Feet of Head}}{\text{1954 feet}} = \frac{\Delta P\ (\text{Const.})}{S}$

This constant equals 0.854 as shown in the following calculation.

$$\frac{\text{Feet of Head}}{\text{1954 feet}} = \frac{(\Delta P)\#/\text{in}^2/\text{mi.})(144\ \text{in}^2/\text{ft}^2)}{S(62.4)\ \#/\text{ft}^3} \times \frac{1954\ \text{ft}}{5280\ \text{ft/mi}}$$

$$= \frac{\Delta P(\text{Const.})}{S}$$

The formula for calculating horsepower is:

$$HP = \frac{QPH}{550e}$$

where: Q = Flow Rate - cu. ft./sec.

P = Density S X Density of Water

H = Feet of Head

e = Efficiency of Pump - 85%

All of the above formulas are used for fluid flow calculations.

An economic formula is required in the analysis for calculating the equivalent annual cost of capital recovery with a return for the pump and the coating. The expression is taken from the Engineering Economy book (Thuesen, 1964).

$$(P-L)\ (RP_{i-n}) + Li$$

where: P = Initial Investment

L = Estimated Salvage Value

i = Interest Rate Before Taxes

n = Life of the Pumping Facilities

In the analysis, L is assumed to be zero and interest rate, i, to be used is 8%. The estimated life, n, of the pump is 20 years and for the coating 15 years.

The second economic formula needed is for power costs. The horsepower required must be converted to kilowatt-hours per year.

$$\text{HP (Const)} = \frac{\text{kilowatt-hours}}{\text{year}}$$

The constant is derived as follows:

$$\frac{\text{HP Kilowatts}}{1.34} \times \frac{1}{3600 \text{ seconds}} \times \frac{3600 \text{ seconds}}{\text{hour}} \times \frac{24 \text{ hrs.}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}}$$

The calculated constant is 6537.3. The cost per kilowatt hour used in this analysis is \$0.009. The total annual power cost formula is:

$$\text{Annual Power Cost} = \text{HP } (6537.3) \times \$0.009$$

Economic Analysis on 4-Inch Test Loop

The first analysis is the determination of the percent reduction of pressure losses necessary to make the internal coating desirable economically for the 4-inch loop. The calculations are made using a flow rate, Q, of 480 barrels per hour. The data used for the analysis is as follows:

10 HP Pump - 85% Efficiency

Internal Diameter of Pipe = 4.163 inches

Length of Test Loop = 1954 feet

Q = 480 barrels per hour - 0.748 cu. ft./sec.

Pumping Costs = \$75/hp

Power Costs = \$0.009/kw. hr.

Coating Cost = \$0.25/sq. ft.

Estimated Life of Pump = 20 years

Estimated Life of Pump = 15 years

The following is a complete economic analysis with the above conditions.

$$R' = \frac{Q}{dz} = \frac{480}{(4.163)(3.45)} = 33.4$$

After the R is calculated, f′ can be read from the Reynolds Number versus Friction Factor curve in Appendix A. With this Reynolds Number, f′ = 0.67. The pressure loss is calculated and converted to feet of head.

$$\Delta P = \frac{f' Q^2 s}{d^5} = \frac{(0.67)\ (480)^2\ (0.8251)}{(4.163)^5}$$

$$= 101.85 \text{ psi/mi}$$

$$\text{Total Head} = \frac{\Delta P(\text{Const})}{S} = \frac{(101.8)(0.854)}{0.8251} = 105.5 \text{ psi/mi}$$

The size of the pump needed to produce 480 barrels per day can now be calculated.

$$HP = \frac{QPH}{550c} = \frac{(0.748)(62.4)(0.8251)(105.5)}{550 \times 0.85} = 8.7$$

Pump sizes are 5, 7.5, 10, and 15 hp. Since an 8.7 hp pump is not available, the next size larger is selected for use. This is the 10 hp pump that will be used in the initial testing.

The annual cost of capital recovery with a return must be calculated for the pump and pump station. The capital recovery factor for an investment with a 20 year life and 8% interest is 0.10185. The initial investment, P, is $750.

$$\text{Cost of Capital Recovery with a return for the pump} = (P-L)\,(RP_{i-n}) + Li$$
$$= (\$750-0)\,(0.10185) + (0)\,(.08)$$
$$= \$76.39/\text{year}$$

Before the total annual cost of the uncoated loop can be calculated, the power cost per year must be determined.

$$\text{Annual Power Cost} = (HP)\,(6537.3)\,(\$0.009)$$
$$= (8.7)\,(6537.3)\,(\$0.009)$$
$$= \$511.87$$

The total annual cost of the uncoated test loop is the sum of the annual cost of capital recovered with a return for the pump and the annual power costs.

$$\text{Total Cost of Uncoated Loop} = \$76.39 + \$511.87$$
$$= \$588.26/\text{year}$$

In order that the annual cost of capital recovery with a return be calculated for the coating, the initial investment, P, must be determined.

$$P = \text{cost/sq.ft.} \times \text{Area (sq. ft.)}$$

$$= \$0.25 \times \left[\frac{\pi d}{12}\right] \times \text{Length (ft.)}$$

$$= \$0.25 \times \left[\frac{(3.14)(4.163)}{12}\right] \times 1954$$

$$= \$532.46$$

The recovery factor for the internal coating is 0.116. The annual cost of capital recovery with a return can now be calculated for the coating.

$$\text{Annual Cost of Capital Recovery with a Return} = (P-L)(RP_{1-n}) + Li$$

$$= (532.46-0)(0.116) + (0)(0.08)$$

$$= \$61.77$$

The total annual costs for coated test loop is the sum of three costs. They are: (1) annual cost of capital recovery with a return for the initial investment of the pump and pump station, (2) annual cost of capital recovery with a return for the initial investment of the coating, and (3) annual power costs. At 0% reduction of pressure losses, the annual cost for the pump and pump station, and the power costs will be the same for the coated and uncoated test loops. The only difference is the total annual cost at

0% reduction is the added cost of the coating. Therefore the total annual cost of the coated loop at 0% reduction or pressure losses is

Total Annual Cost of Coated Test Loop with a 0% Reduction of Pressure Drop	= Annual Cost(Uncoated loop) + Annual Coating Cost	
	= \$588.26 + \$61.77	
	= \$650.03	

In order to show the break even point for the two curves, the uncoated and the coated, a break even curve is shown in Figure 1, page 12. The curve is produced by plotting total annual costs of the two loops versus percent reduction of pressure losses. Since no change in the pressure loss is assumed for the uncoated test loop, the curve is a straight line.

The total annual costs at 0, 10, 15, and 20% reduction of pressure losses are plotted for the coated test loop. At 0% reduction, the annual cost of the coated test loop is \$650.03. As the percent reduction increases, the annual cost decreases as shown in Figure 1. The following calculations illustrate the decreasing annual cost for the coated test loop.

With a 10% reduction of pressure losses the head is reduced to 94.9 feet. The horsepower required is calculated as in previous calculations.

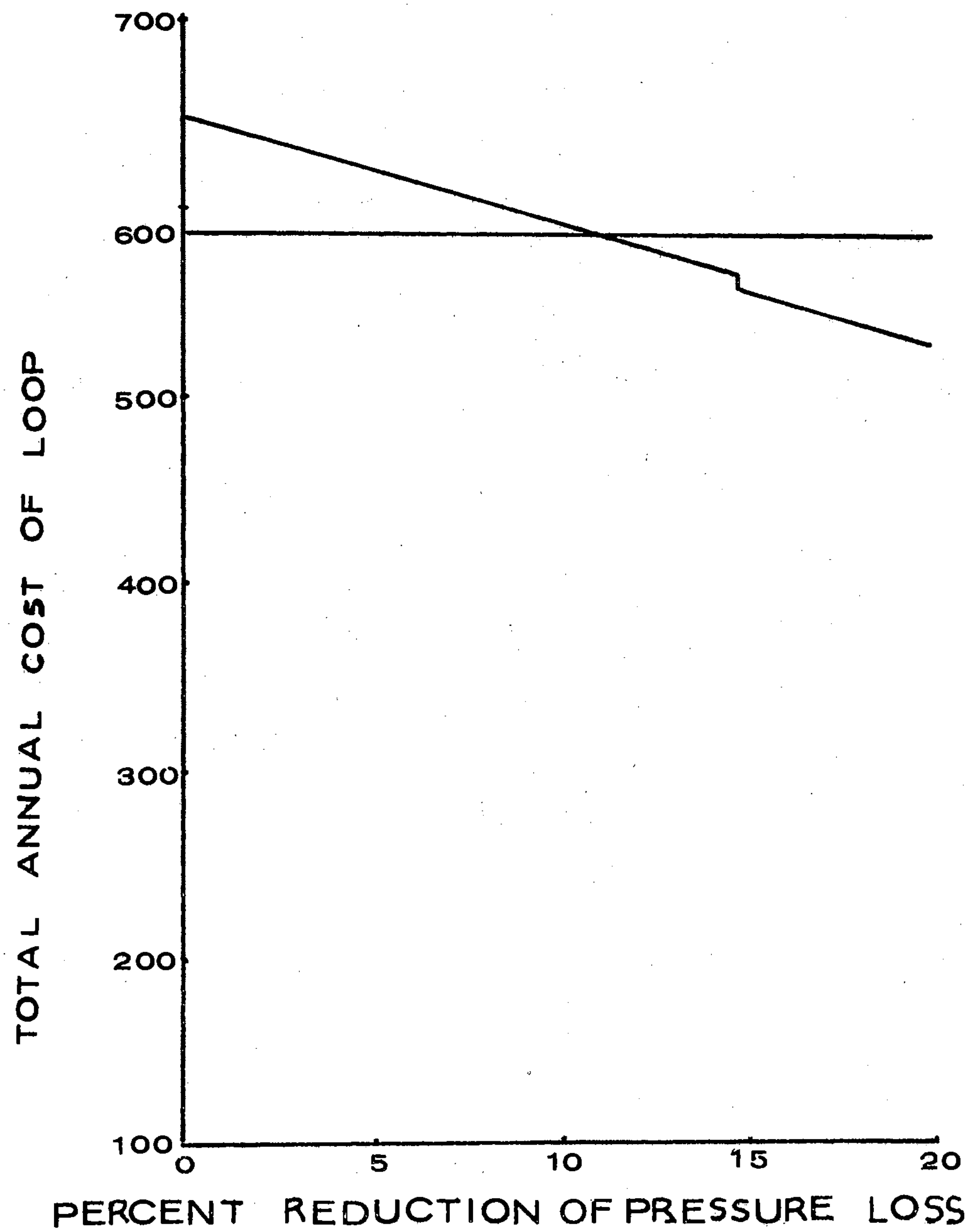

Figure 1. Break-even Curve for 4-Inch Test Loop

$$HP = \frac{QPH}{550c} = \frac{(0.748)\ (62.4)\ (0.8251)\ (94.9)}{550 \times 0.85}$$

$$= 7.8$$

If the 10% reduction had reduced the horsepower requirement to 7.5 hp, the pump size could have been reduced to 7.5 hp. With the requirements of 7.8 hp, the system still requires the 10 hp pump. Therefore the annual cost of capital recovery with a return for the pump remains unchanged. The only change will be a decrease in power costs as shown:

$$\text{Annual Power Cost} = (HP)\ (6537.3)\ (\$0.009)$$
$$= (7.8)\ (6537.3)\ (\$0.009)$$
$$= \$458.92$$

Therefore the total annual cost of the uncoated test loop with a 10% reduction of pressure losses is

Total Annual Cost of Coated Test Loop with a 10% Reduction of Pressure Losses = Annual Cost of Capital Recovery with a Return for Pump + Power Costs + Annual Cost of Capital Recovery with return for Coating

$$= \$76.39 + \$458.92 + \$61.77$$

$$= \$597.08$$

The total annual cost of the coated test loop will also be calculated for reductions of 15 and 20% of the pressure losses. With a 15% reduction the head will be reduced to 90.7 feet. Substituting this head into the horsepower equation, one obtains

$$HP = \frac{QPH}{550c} = \frac{(0.748)\ (62.4)\ (0.8251)\ (90.7)}{550 \times 0.85}$$

$$= 7.5$$

As previously stated, pumps come in sizes of 5, 7.5, 10, and 15 hp. With the reduction of the horsepower requirements to 7.5 horsepower, a smaller size pump can be selected. The 15% reduction is the point where the switch is made from a 10 hp to a 7.5 hp pump. In Figure 1 this change of pump size is shown by a drop of the coated cost curve at 15%. This is the result of a large decrease in pump costs.

With the change in the size of the pump, a new annual cost of capital recovery with a return must be calculated for the pump. The initial investment is $562.50.

Annual Cost of Capital Recovery with a Return for 7.5 hp pump $= (P-L)\ (RP_{i-n}) + Li$

$= (562.50-0)\ (0.10185)+(0)(0.08)$

$= \$57.29$

A new annual power cost will be calculated.

Annual Power Cost $= (HP)\ (6537.3)\ (\$0.009)$

$= \$441.27$

The annual coating cost remains unchanged since the pipe line used in this analysis is the same. The formula used to calculate the total annual cost for the coated loop, with a 15% reduction of pressure losses, is the same formula used in the previous calculations for the 10% reduction shown on page 12. Therefore the total annual cost of the coated test loop with a 15% reduction or pressure losses equals

Total Annual Cost of Coated Loop with a 15% reduction $= \$57.29 + \$441.27 + \$61.77$

$= \$560.33$

Calculations of the total annual costs for the coated loop with a 20% reduction are made using the same equations as those used in calculating the total annual cost with a 10 and 15% reduction. With a 20% reduction of pressure losses, the head is reduced to 84.4. Substituting the head into the horsepower formula, a new horsepower requirement is obtained.

$$HP = \frac{QPH}{550c} = \frac{(0.748)\ (62.4)\ (0.8251)\ (84A)}{550 \times 0.85}$$

$$= 7$$

A 7.5 hp pump is still required so the annual cost of capital recovery with a return for the initial investment of the pump remains unchanged. However the power costs will decrease due to the lower horsepower requirements.

$$\text{Annual Power Cost} = (\text{HP})\ (6537.3)\ (\$0.009)$$
$$= (7)\ (6537.3)\ (\$.009)$$
$$= \$411.85$$

The total annual cost of the coated loop with a 20% reduction is

$$\begin{matrix}\text{Total Annual Cost}\\ \text{of the Coated Loop}\end{matrix} = \$57.29 + \$411.85 + \$61.77$$
$$= \$530.91$$

After all calculations had been made, the points were plotted to produce the curves shown in Figure 1, page 12. The curves reveal a break even point of 11% reduction in pressure drop is required in order for the coating of the 4-inch test loop to be economically desirable.

An investigation will be made to determine the affect, of varying the flow rate, Q, on the percent reduction necessary to make coating economically desirable. The only variable changed in this analysis is the flow rate. It is raised to 600 barrels per hour or 0.936 cu. ft/sec. The calculations are the same as the previous analysis.

$$R' = \frac{Q}{\partial z} = \frac{600}{(4.163)\ (3.45)} = 42$$

$$f' = 0.54$$

$$\Delta P = \frac{(f')\ (Q)^2\ \ (S)}{\partial^5} = \frac{(0.54)(600)^2\ (0.8251)}{(4.163)^5} = 128 \text{ psi/mi}$$

Convert psi/mi to $\frac{\text{feet of head}}{1954'} = \frac{(\Delta P)(\text{Const})}{S} = \frac{(128)(0.854)}{0.825'} = 132$ ft.

The horsepower requirements can now be calculated.

$$HP = \frac{(Q)\ (P)\ H}{550c} = \frac{(0.936)\ (0.8251)\ (62.4)\ (132)}{550 \times 0.85} = 13.6 \text{ hp.}$$

Since a 13.6 hp pump is not available, the next size larger is chosen. A 15 hp pump is required for this analysis. The initial investment, P, is $1125. Therefore the annual cost of capital recovery with a return for the pump is

Annual Cost of Capital Recovery with a Return for Pump $= (P-L)\ (RR_{i-n}) + Li$

$$= [(1125)-0]\ (0.10185) + (0)(0.08)$$

$114.58

With the increase of horsepower requirements, a new power cost per year must be determined.

Annual Power Cost $= (HP)\ (\text{Const})\ (\$0.009)$

$= (13.6)\ (6537.3)\ (\$0.009)$

$= \$800.16$

The total annual cost for the uncoated loop can be calculated. The formula used is the same as that used in the previous analysis on page 9.

$$\text{Total Annual Cost (Uncoated Loop)} = \$114.58 + \$800.16$$

$$= \$915.08$$

Since the line size is constant the coating costs are unchanged. The coating cost per year is $61.77. With an 8% reduction of head, it is lowered to 121.4 feet. The horsepower can now be calculated.

$$HP = \frac{QPH}{550c} = \frac{(0.936)\ (0.8251)\ (62.4)\ (121.4)}{550 \times 0.85}$$

$$= 12.5$$

The next size larger pump available is a 15 hp pump. Since the same size pump required with the reduction as in the uncoated loop, the pumping costs remain the same. However, the power costs will change.

$$\text{Annual Power Cost} = (\text{HP})\ (\text{Const})\ (\$0.009)$$

$$= (12.5)\ (6537.3)\ (\$0.009)$$

$$= \$739.00$$

With the three costs determined, the total annual cost for the coated loop can be calculated.

$$\text{Total Annual Cost (Coated Loop)} = \$114.58 + \$739 + \$61.77$$

$$= \$915.35$$

Comparing the two costs, it can be seen that the 8% reduction of pressure losses is the break even point. Therefore, increasing the flow rate, decreased the percent pressure loss reduction required to justify coating economically.

In the following analysis the variable, diameter, is reduced to 2.157 inches and the other variables remain constant. An analysis is made to determine the affect of changing the diameter of the pipe. The analysis is as follows:

$$R' = \frac{Q}{dz} = \frac{480}{(2.157)(3.45)} = 64.6$$

$$f' = 0.59$$

$$\Delta P = \frac{f'(Q^2 s)}{d^5} = \frac{(0.59)\ (480)^2 (0.8251)}{(2.157)^5}$$

$$= 2400 \text{ psi/mi}$$

It should be noted that the decrease in diameter caused a large increase in the head. With this large increase in head, a much larger pump will be required. The following calculations show

$$\text{Head} = \frac{(\Delta P)(\text{Const})}{s} = \frac{(2400)(0.854)}{0.8251} = 2480 \text{ ft.}$$

$$HP = \frac{QPH}{550c} = \frac{(0.748)(0.8251)(62.4)(2480)}{550 \times 0.85} = 204$$

Larger pumps come in sizes of 200, 300, 400, and 500 hp. Therefore a 300 hp pump must be purchased to produce 204 hp. Any pump between 200 - 800 hp costs \$150/hp. Therefore the initial investment is \$45,000. The annual cost of capital recovery with a return can be calculated for the pump and the pump station.

Annual Cost of Capital Recovery With a Return for Pump $= (P-L)\ (RP_{i-n})\ (0.10185) + Li$

$= (45{,}000 - 0)\ (0.10185) + 0(.08)$

$= \$4583.25$

With the large increase in the size of the pump, the annual power cost will also increase.

Annual Power Cost $= (HP)\ (Const)\ (\$0.009)$

$= (204)\ (6537.3)\ (\$0.009)$

$= \$12{,}002.51$

Now that the annual pump costs and the costs have been calculated, the total annual cost for the uncoated loop can be determined.

Total Annual Cost (Uncoated Loop) $= \$4583.25 + \$12{,}002.51$

$= \$16{,}585.76$

The annual cost of capital recovery with a return for the initial investment of coating is

Initial Investment $=$ cost/sq.ft. X area (sq. ft.)

$= \$0.25 \times \frac{(3.10)\ (2.157)}{12} \times 1954$

$= \$307.75$

Annual Cost of Capital Recovery with Return for Coating $= (P-L)(RP_{i-n}) + Li = (307.75-0)(0.116) + (0)\ (.08)$

$= \$35.70$

The coating cost is a very small number compared to the cost of the uncoated test loop. The percent reduction is approximately zero. Lowering the diameter of the pipe increases the head or pressure loss, and therefore reduces the percent reduction of pressure loss required to make coating economically desirable.

Test Procedure

Once the break-even point is determined, the next step is to test what the actual reduction in pressure drop will be and compare these figures. Determination of the actual reduction in pressure drop was accomplished by the following procedure.

All tests were performed at the Continental Pipe Line Company research facilities located in Ponca City, Oklahoma. The test loop layout is shown in Figure 2 on page 22.

Pressure losses were measured over a calibrated length of line with pressure gauges which had been dead-weight tested. In the 2-inch loop there was 1,944 feet between the pressure taps, and in the 4-inch loop, there was 1,954 feet between the taps. The line in the calibrated section was free from any valves or restrictions, and the 180 degree return was made with a long radius shop bend.

Flow rates were measured using a 200-gallon weight

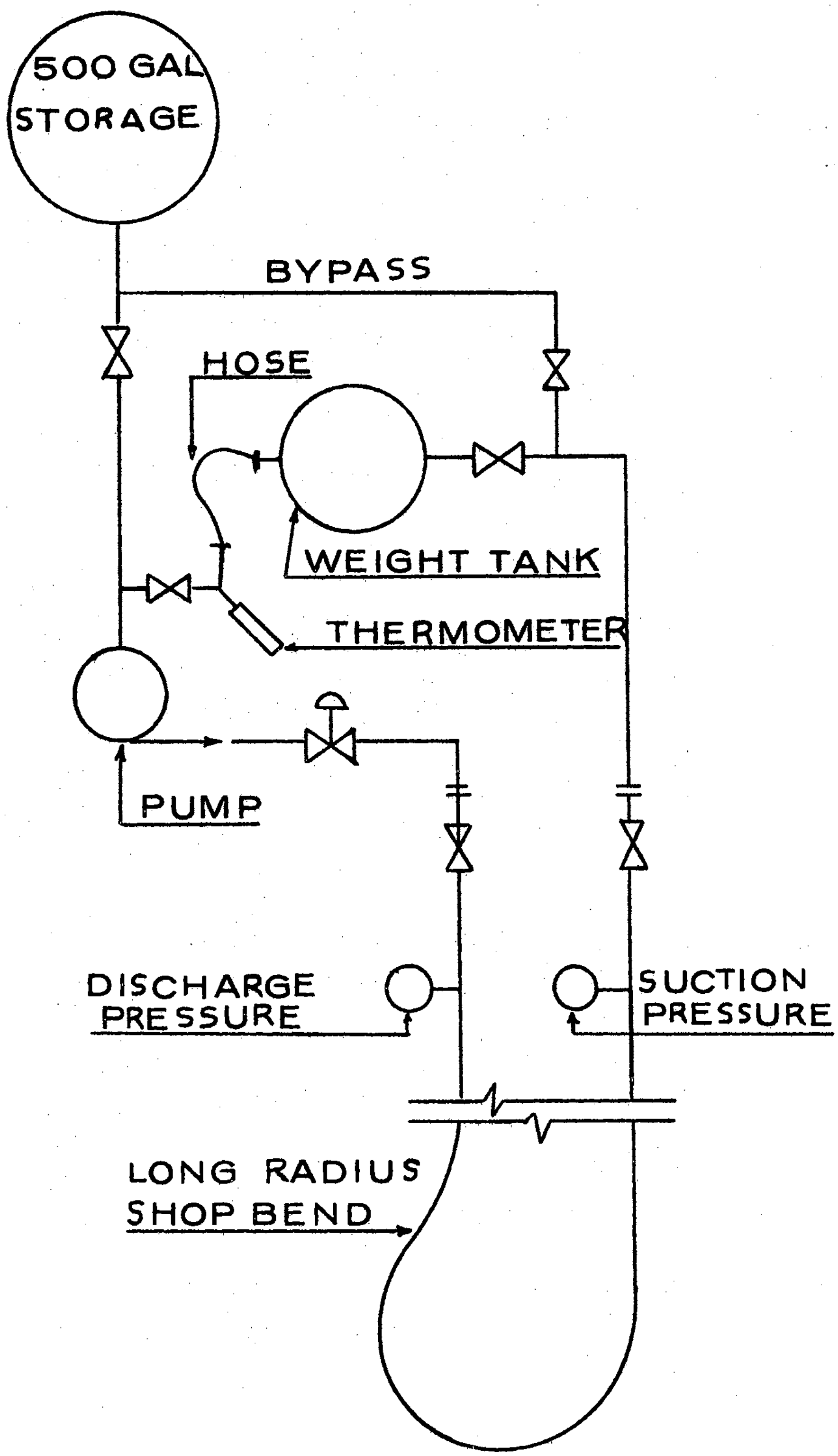

Figure 2. Test Loop Layout

tank mounted on scales and connected to the system with rubber hoses. The time required to pump 500 pounds into the weight tank was used for all rate calculations.

Temperature and specific gravity readings were recorded in the field, and samples were sent to the refinery laboratory for viscosity tests on each run made. Results from these viscosity tests are shown in Appendix D.

The test sequence, identical in both the uncoated and coated tests, was as follows:

1. The control valve on the pump discharge was set to give an approximate pressure differential desired as a test point.
2. The flow was allowed to stabilize while flowing through the weight-tank bypass.
3. The flow was switched into the weight-tank and timing started after the scales tipped at 200 pounds.
4. While timing, the suction and discharge gauges were read simultaneously.
5. When the scales tipped at 700 pounds, the timing was stopped.
6. The pump suction was switched from the storage tank to the weight-tank and the weight-tank was pulled down until the remaining fluid weighed less than 200 pounds. While draining the weight-tank, the

temperature was measured with an in-line thermometer.

7. After draining operations were complete, the pump suction was switched back to the storage tank; and a new pressure differential was set with the control valve.

8. Prior to any calculations, the pressure readings were corrected with charts previously made up by comparing gauge reading against a dead weight tested over the full range of the guage.

These steps were repeated during incremental changes over the full range of flow rates available with the existing pumping equipment. In most cases, points were repeated with good correlation.

Because of limited pumping capacity, there was a relatively small range of flow rates available in the 4-inch loop. Also, at low flow rates in the 4-inch system, there was little differential in 1,954 feet; and results from tests where both discharge and suction pressure were less than 10 psi were normally not plotted. Since the pressures were small, slight variations due to reading errors or surges gave excessive variation in the final data taken from readings at low flow rates in the 4-inch line.

After the uncoated tests were complete, the internal coating was done by a crew using their own lining material, coating methods, and equipment. The coating was visually inspected as much as possible and seemed to be of good quality with no streaks or uncoated areas. After all testing operations were complete, the coated loops were cut in several places and small sections inspected. The coating was about as smooth as could be expected from an in-place coating technique.

CHAPTER III

RESULTS AND CONCLUSIONS

Results of Tests

Considering all test data, it is concluded that the internal coating tested decreased pressure losses less than 1% from those experienced on an uncoated line. The data from the crude runs is very consistent. Log-log graphs of pressure loss versus flow rate are included in Figures 3 - 5, pages 27-29, and actual test data are included in Appendixes B and C.

Tests on crude gave identical results on both the coated and uncoated loops except for the 2-inch crude runs which indicated a slightly smaller pressure loss in the coated loop.

It should be noted, since the uncoated and coated tests were performed as much as a month apart, a different batch of fluid was used in each of the runs. The most noticeable difference was in the viscosity characteristics. Graphs of viscosity are shown in Appendix D. Since the fluid used in the uncoated and coated tests was not

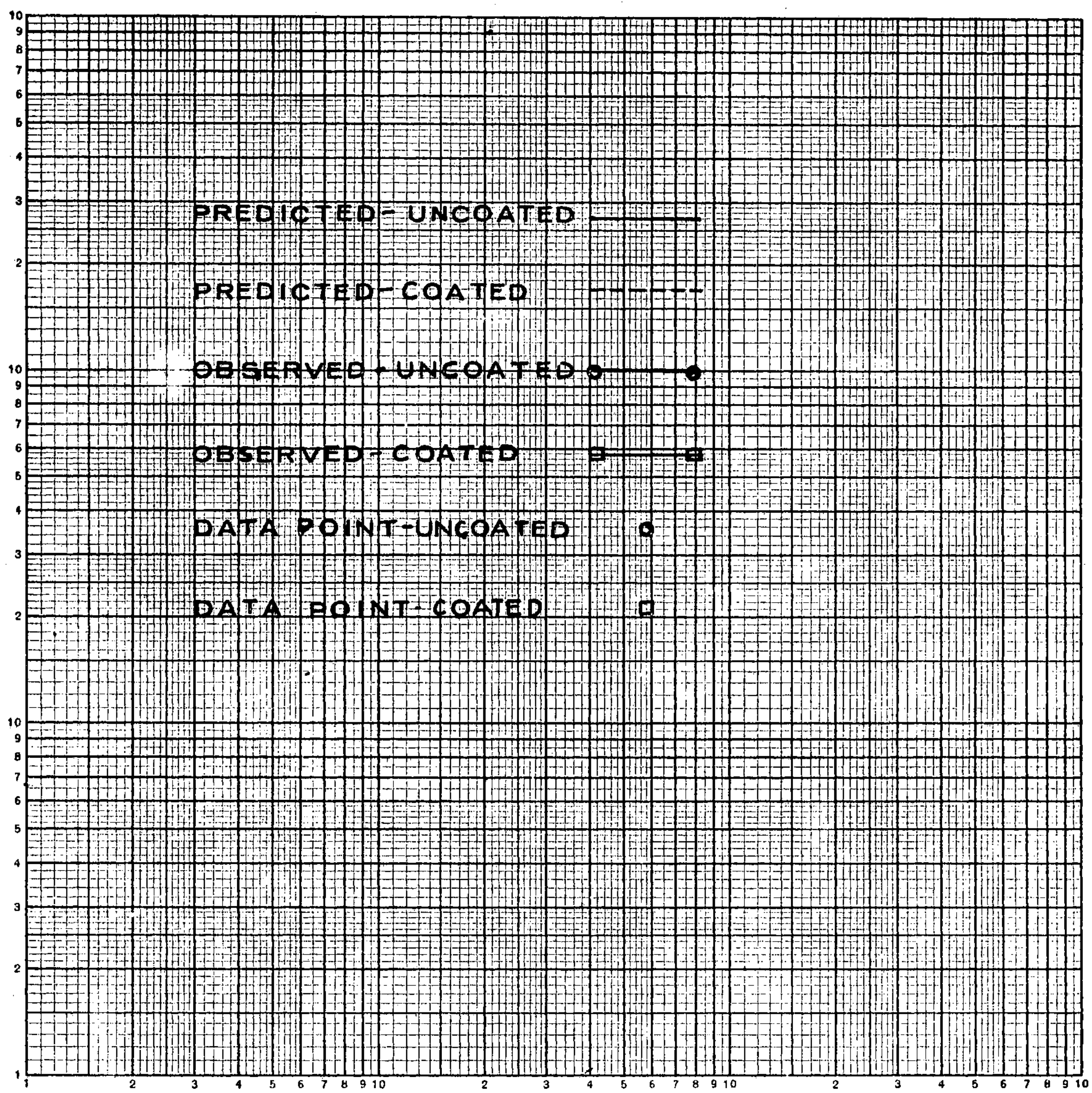

Figure 3. Index for Figures 4 and 5

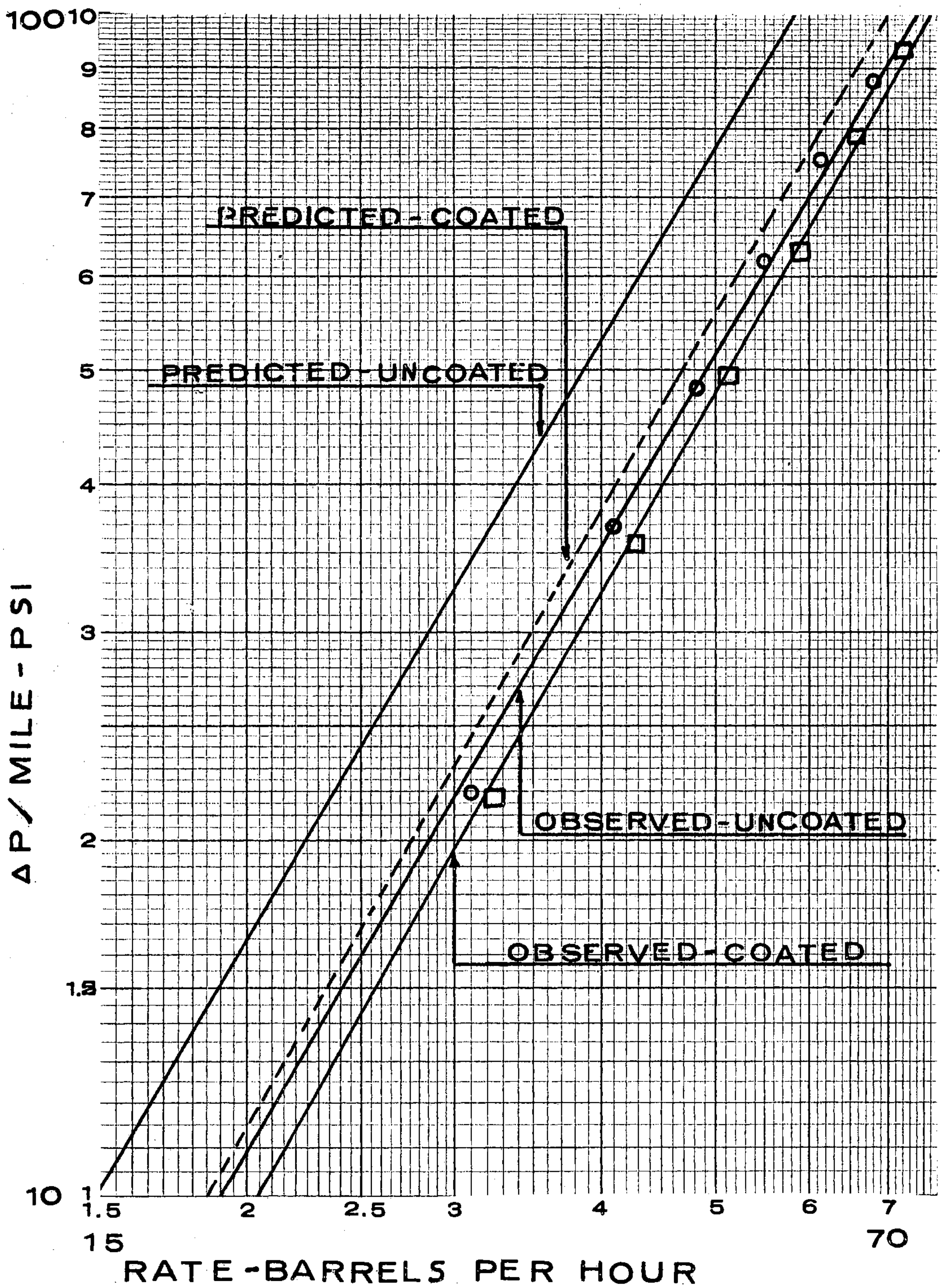

Figure 4. Log-Log Graph or Pressure Loss Versus Flow Rate for Crude on 2-Inch Loop

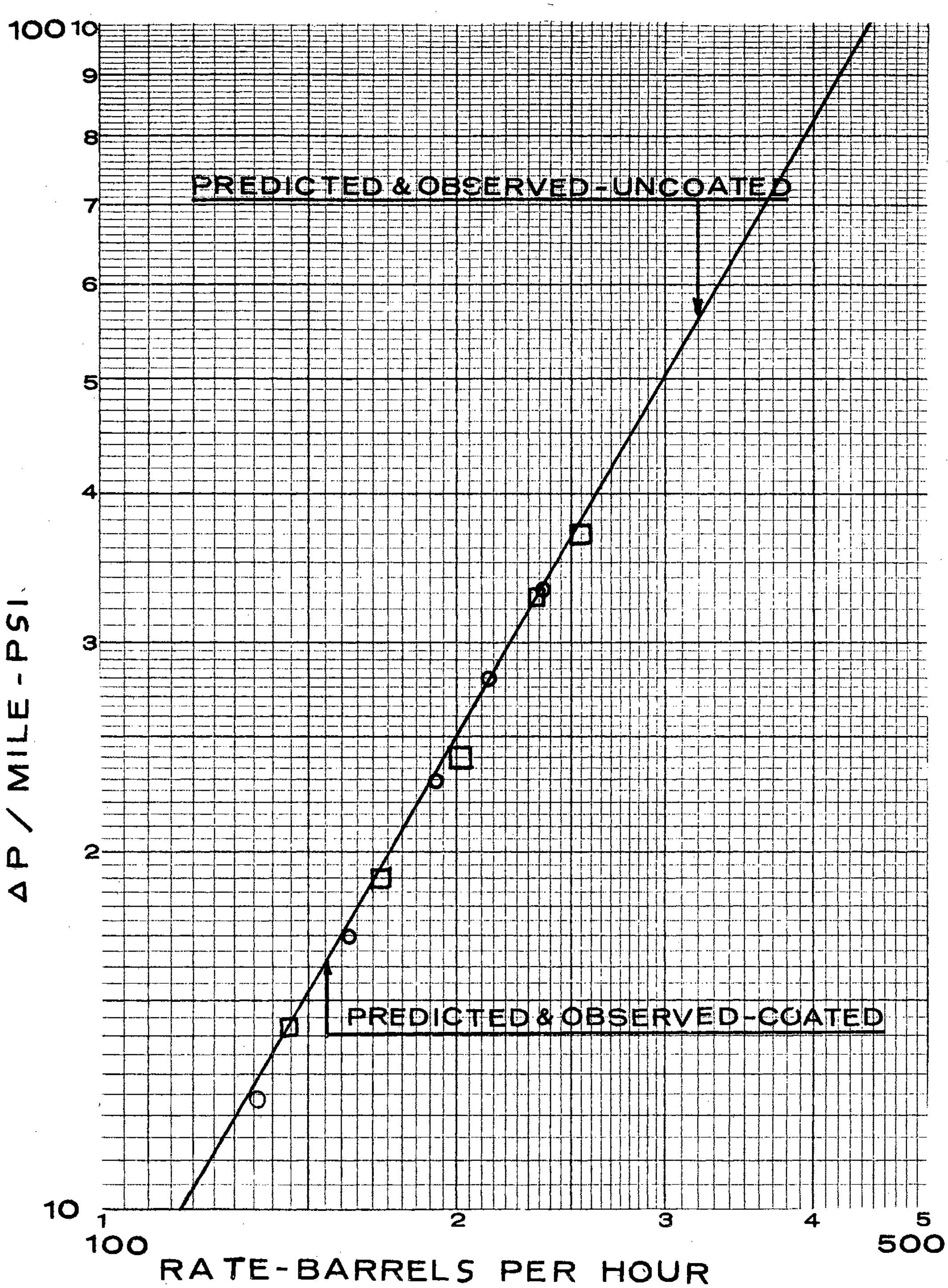

Figure 5. Log-Log Graphs of Pressure Loss Versus Flow Rate for Crude on 4-Inch Loop

identical, the results cannot be compared directly. To overcome this problem, a predicted loss is computed using the "Pipe Line News" method (a simplification of the Darey Weisback equation) with the actual observed specific gravity, viscosity, and rate. The formulas of this method are given in Chapter 2. Deviations between the observed pressure loss and the predicted loss for the two cases can be compared directly. These deviations are included in the test data shown in Appendixes B and C.

It should be pointed out that the f', "Pipe Line News", used in calculating the predicted pressure drop can be read from the curve in Appendix A, after R' is calculated.

The values for the predicted losses in both the uncoated and the coated loops are arrived at in the same manner. In other words, when predicting pressure losses, the coated loops are not given any credit for any reduction in ΔP that might occur because of epoxy lining. It should be noted that the predicted ΔPs for uncoated and coated in the same loop on the same product are in some cases different, as shown in Figures 3 - 5. This is due to temperature change, and therefore product viscosity between the uncoated and coated tests.

As a matter of interest, pressure losses predicted by using the "Pipe Line News" method are conservative, averaging approximately 20% high on crude in the 2-inch uncoated loop. Losses predicted in the uncoated 4-inch loop on crude oil are identical to those observed.

Since no significant differences are measured between the uncoated and coated losses, no attempt will be made to predict differences in other size lines.

Conclusion

The economic analysis shows a break-even point of 11% is needed to make coating economically desirable. However, the actual tests show a reduction of less than 1% in pressure loss if coated pipe is used. Consequently, the idea of coating pipe to reduce pressure loss is not economically desirable. If the reduction had been greater than 11%, it would be desirable to coat, otherwise it would not.

As pipe ages, the internal surface deteriorates. With this deterioration, the diameter enlarges and the relative roughness increases. As the relative roughness increases, so does the resistance coefficient, f', resulting in larger pressure losses at any given flow conditions above laminar flow.

An area for investigation is the possible reduction of this deterioration by coating the internal surface of the pipe. Two identical pipe lines, one coated and one uncoated could be built for testing. After 4 or 5 years, each pipe line could be tested to determine if the coating reduced the deterioration and therefore reduced the pressure losses. An economic analysis would have to be made to determine the percent reduction of the deterioration necessary to make the coating economically desirable.

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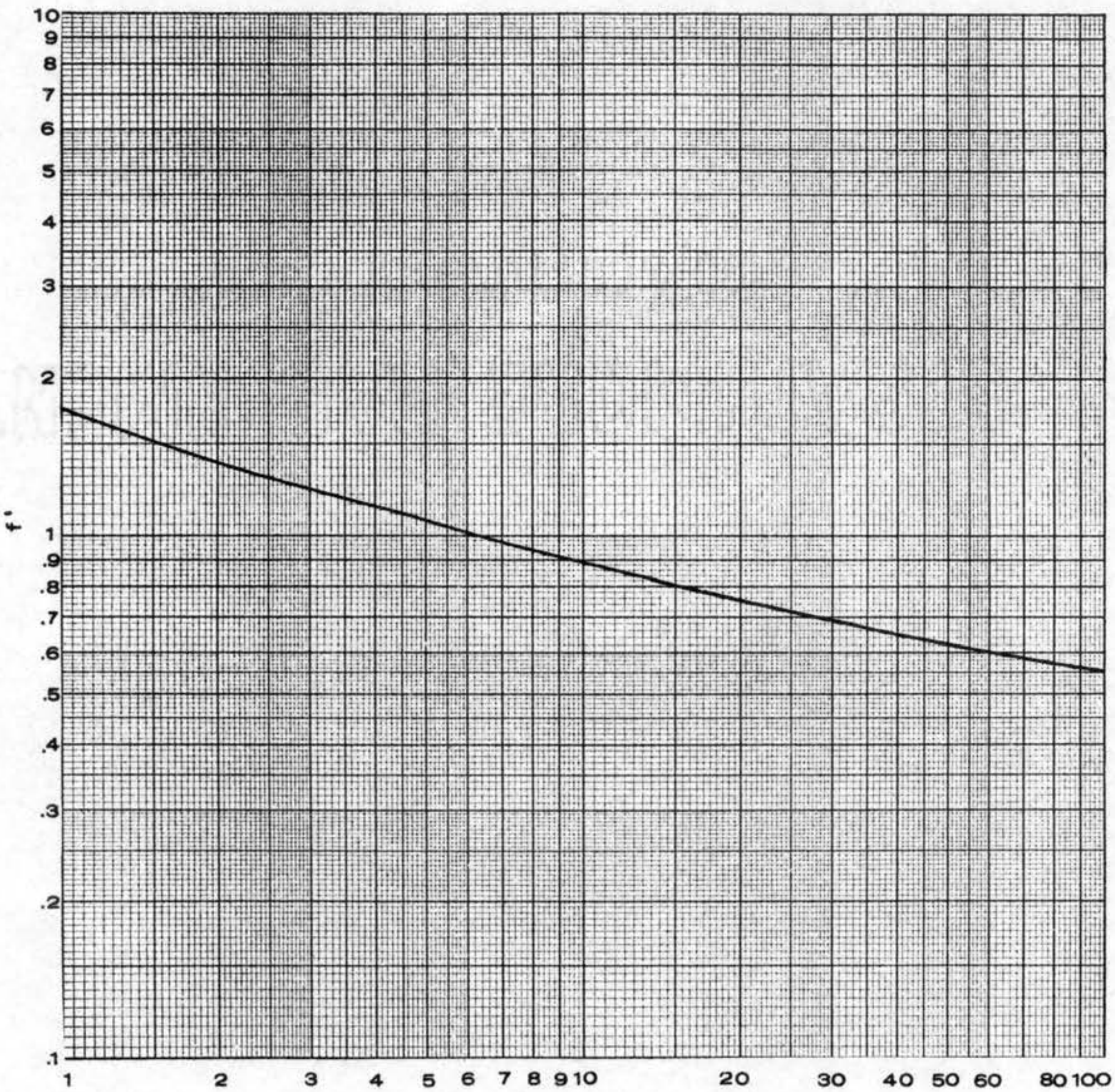
APPENDIX A

FRICTION FACTOR VERSUS REYNOLDS NUMBER CURVE

FRICTION FACTOR VS. REYNOLDS NUMBER



APPENDIX B

UNCOATED TEST LOOP DATA

INTERNALLY COATED PIPE HYDRAULICS TEST - UNCOATED TESTS ON CRUDE

Run No.	SUCTION PRESSURE Gauge	SUCTION PRESSURE Corrected Gauge	DISCHARGE PRESSURE Gauge	DISCHARGE PRESSURE Corrected Gauge	ΔP (psi) / 1,944'	ΔP (psi) / Mile	Time/500-Lb.	Observed Temperature Degrees F	Specific Gravity at Observed Temp.	Rate (BPH)	Viscosity (Cs) at Observed Temperature	f' Observed	R' Observed	f' Pipe Line News Method	ΔP (psi)/Mile Pipe Line News Method	Percent Deviation Observed Vs. Predicted
2-INCH LOOP (1,944 FT.)																
1	2.60	2.45	44.10	44.36	41.91	113.83	1'19.0"	72.7	.8289	78.61	12.30	.838	3.09	1.22	165.64	-31.28
2	2.40	2.27	39.50	39.78	37.51	101.88	1'25.0"	72.7	.8289	73.06	12.30	.869	2.87	1.25	146.59	-30.50
3	2.30	2.18	34.40	34.53	32.35	87.86	1'31.3"	72.7	.8289	68.02	12.30	.864	2.68	1.27	129.10	-31.94
4	2.10	2.00	29.50	29.50	27.50	74.69	1'40.3"	72.7	.8289	61.92	12.30	.887	2.44	1.31	110.35	-32.32
5	1.90	1.82	24.30	24.30	22.48	61.06	1'51.6"	72.7	.8289	55.59	12.30	.899	2.19	1.35	91.66	-33.38
6	1.60	1.54	19.30	19.29	17.75	48.21	2'8.4"	72.7	.8289	48.37	12.30	.938	1.90	1.41	72.48	-33.49
7	1.50	1.45	14.90	14.85	13.40	36.40	2'32.0"	72.7	.8289	40.87	12.30	.992	1.61	1.50	55.05	-33.87
8	1.30	1.27	9.40	9.29	8.02	21.78	3'18.8"	72.7	.8289	31.25	12.30	1.015	1.23	1.63	34.97	-37.72
9	1.10	1.08	5.20	5.20	4.12	11.19	4'42.0"	72.7	.8289	22.03	12.30	1.049	.87	1.84	19.62	-42.97
															Average =	-34.16%
4-INCH LOOP (1,954 FT.)																
1	14.40	14.30	26.60	26.60	12.30	33.40	26.4"	103.6	.8251	237.04	3.45	.785	16.96	.780	33.19	+.63
2	11.60	11.55	21.85	21.85	10.30	27.97	29.4"	103.6	.825	212.89	3.45	.815	15.24	.805	27.63	+1.23
3	9.40	9.30	17.70	17.70	8.45	22.95	33.0"	103.6	.825	191.23	3.45	.828	13.69	.825	22.84	+.48
4	7.00	7.00	13.20	13.23	6.23	16.92	38.6"	103.6	.825	162.23	3.45	.849	11.61	.860	17.14	-1.28
5	4.80	4.70	9.00	9.00	4.30	11.68	47.8"	103.6	.825	130.95	3.45	.900	9.37	.905	11.75	-.60
6	2.80	2.69	5.35	5.35	2.66	7.22	1'04.0"	103.6	.825	97.85	3.45	.996	7.00	.975	7.07	-2.12
7	1.30	1.27	2.45	2.45	1.18	3.20	1'51.1"	103.6	.825	56.32	3.45	1.333	4.03	1.130	2.71	-18.08
															Average of Those Plotted =	+0.09%

APPENDIX C

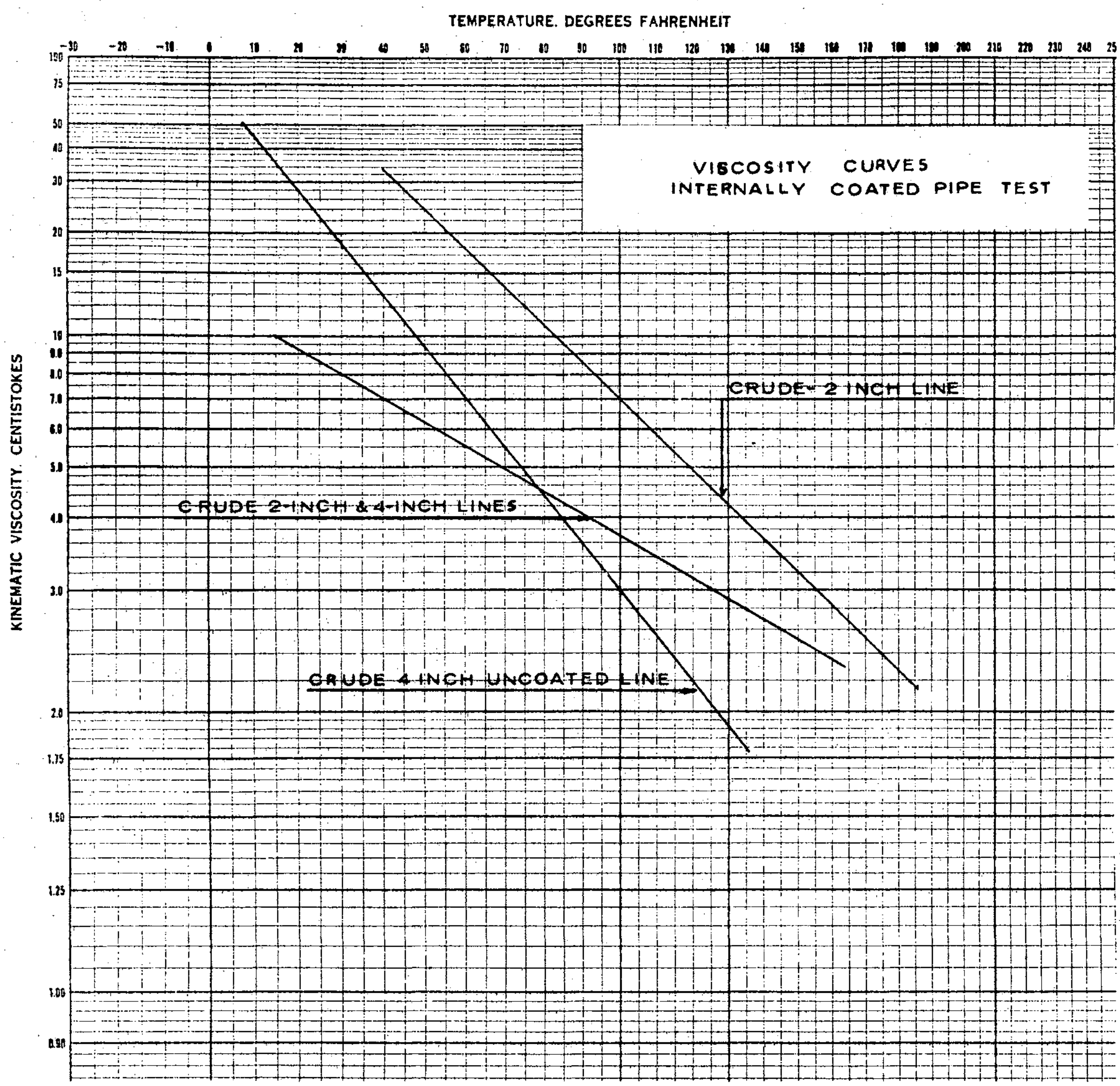
COATED TEST LOOP DATA

INTERNALLY COATED PIPE HYDRAULICS TEST - COATED TESTS ON CRUDE

Run No.	SUCTION PRESSURE Gauge	SUCTION PRESSURE Corrected Gauge	DISCHARGE PRESSURE Gauge	DISCHARGE PRESSURE Corrected Gauge	ΔP (psi) 1,944'	ΔP (psi) Mile	Time/500-Lb.	Observed Temperature Degrees F	Specific Gravity at Observed Temp.	Rate (BPH)	Viscosity (Cs) at Observed Temperature	f' Observed	R' Observed	f' Pipe Line News Method	ΔP (psi)/Mile Pipe Line News Method	Percent Deviation Observed Vs. Predicted
2-INCH LOOP (1,944 FT.)																
1	2.5	2.37	43.3	43.57	41.20	111.90	1'19.2"	86.0	.8063	80.80	3.85	.779	10.21	.885	127.12	-11.97
2	2.3	2.19	36.8	37.00	34.81	94.55	1'27.3"	86.0	.8063	73.30	3.85	.800	9.26	.910	107.57	-12.10
3	2.1	2.00	30.5	30.50	28.50	77.41	1'37.1"	86.0	.8063	65.92	3.85	.810	8.33	.935	89.39	-13.40
4	2.0	1.91	25.0	25.00	23.09	62.71	1'48.8"	86.0	.8063	58.83	3.85	.824	7.44	.960	73.10	-14.21
5	1.8	1.73	19.9	19.90	18.17	49.35	2'4.7"	86.0	.8063	51.33	3.85	.851	6.49	.995	57.68	-14.44
6	1.6	1.54	14.7	14.65	13.11	35.61	2'29.6"	86.0	.8063	42.78	3.85	.884	5.41	1.040	41.88	-14.97
7	1.3	1.27	9.4	9.30	8.03	21.81	3'16.4"	86.0	.8063	32.59	3.85	.933	4.12	1.120	26.17	-16.66
8	1.1	1.08	4.9	4.70	3.62	9.83	5'10.0"	86.0	.8063	20.65	3.85	1.048	2.61	1.280	12.01	-18.15
9	2.4	2.28	36.8	37.00	34.72	94.30	1'26.7"	86.0	.8063	73.81	3.85	.787	9.33	.910	109.07	-13.54
															Average =	-14.38%
4-INCH LOOP (1,954 FT.)																
1	19.8	19.77	33.5	33.38	13.61	36.78	25.1	86.1	.8063	255.17	3.85	.763	16.36	.790	38.06	-3.36
2	16.7	16.65	28.8	28.80	12.15	32.83	27.5	86.1	.8063	232.88	3.85	.818	14.93	.805	32.30	+1.64
3	12.8	12.83	21.7	21.70	8.87	23.97	32.1	86.1	.8063	199.37	3.85	.816	12.79	.840	24.70	-2.96
4	10.0	10.04	17.1	17.07	7.03	19.00	37.0	86.1	.8063	172.98	3.85	.860	11.09	.850	18.82	+.96
5	7.5	7.5	12.9	12.8	5.30	14.32	43.9	86.1	.8063	145.79	3.85	.910	9.35	.905	14.23	+.63
6	4.8	4.8	8.2	8.00	3.20	8.64	56.7	86.1	.8063	112.87	3.85	.916	7.24	.970	9.14	+5.47
7	2.6	2.50	4.4	4.10	1.60	4.32	1'25.9"	86.1	.8063	74.50	3.85	1.051	4.78	1.075	4.38	-1.37
															Average of Those Plotted =	-0.62%

APPENDIX D

VISCOSITY CURVES


TEMPERATURE, DEGREES FAHRENHEIT
KINEMATIC VISCOSITY, CENTISTOKES
VISCOSITY CURVES
INTERNALLY COATED PIPE TEST
CRUDE- 2 INCH LINE
CRUDE 2-INCH & 4-INCH LINES
CRUDE 4 INCH UNCOATED LINE

VITA

Kenneth Craig Watkins

Candidate for the Degree of

Master of Science

Thesis: A STUDY OF THE ECONOMIC DESIRABILITY OF INTERNALLY COATING PIPE TO REDUCE PRESSURE LOSSES

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